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Modelling and mapping heavy metal and nitrogen concentrations in moss in 2010 throughout Europe by applying Random Forests models

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HIGHLIGHTS

- Comprehensive analysis of relations between atmospheric deposition and accumulation.
- Random Forests (RF) allows for multiple regression analysis.
- Atmospheric deposition, land use and distance to emission sources are relevant factors.
- Measured elements, countries and ecological land classes determine the models accuracy.
- RF enables predictive mapping of element concentrations in moss.

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ABSTRACT

Objective: This study explores the statistical relations between the concentration of nine heavy metals (HM) (arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), vanadium (V), zinc (Zn)), and nitrogen (N) in moss and potential explanatory variables (predictors) which were then used for mapping spatial patterns across Europe. Based on moss specimens collected in 2010 throughout Europe, the statistical relation between a set of potential predictors (such as the atmospheric deposition calculated by use of two chemical transport models (CTM), distance from emission sources, density of different land uses, population density, elevation, precipitation, clay content of soils) and concentrations of HMs and nitrogen (N) in moss (response variables) were evaluated by the use of Random Forests (RF) and Classification and Regression Trees (CART). Four spatial scales were regarded: Europe as a whole, ecological land classes covering Europe, single countries participating in the European Moss Survey (EMS), and moss species at sampling sites. Spatial patterns were estimated by applying a series of RF models on data on potential predictors covering Europe. Statistical values and resulting maps were used to investigate to what extent the models are specific for countries, units of the Ecological Land Classification of Europe (ELCE), and moss species.
Results: Land use, atmospheric deposition and distance to technical emission sources mainly influence the element concentration in moss. The explanatory power of calculated RF models varies according to elements measured in moss specimens, country, ecological land class, and moss species. Measured and predicted medians of element concentrations agree fairly well while minima and maxima show considerable differences. The European maps derived from the RF models provide smoothed surfaces of element concentrations (As, Cd, Cr, Cu, N, Ni, Pb, Hg, V, Zn), each explained by a multivariate RF model and verified by CART, and thereby more information than the dot maps depicting the spatial patterns of measured values.
Conclusions: RF is an eligible method identifying and ranking boundary conditions of element concentrations in moss and related mapping including the influence of the environmental factors.

1. Introduction

Enhanced atmospheric deposition and correlated concentrations of HM and N may cause serious problems for human health and ecosystem integrity (Bobbink et al., 2010). The degree of pollution may be explored by determining element concentrations in the air, water, soil, or sediments. Alternatively, or complementarily, monitoring organisms (bioindicators, biomonitors) are used for monitoring and mapping spatial patterns of element concentrations (Markert et al. 2003) or further analysis, e.g. by use of multivariate analysis (Factor analysis (FA) and/or Principal component analysis (PCA)) (Špirić et al., 2013). Such organisms might accumulate many elements to measurable concentrations indicating an average degree of pollution over time. The concentration in the monitoring organisms reflects the element fraction available for uptake by organisms (Bjerregaard et al., 2015). Mosses used for this study are ectohydric and absorb water over the plant surface. Mosses receive and accumulate elements directly from the atmosphere via wet, occult and dry atmospheric deposition (Glime, 2006). Therefore, chemical analyses of moss specimens provide a surrogate, time-integrated measure of the spatial patterns of element deposition. Biomonitoring using mosses is easier and cheaper than deposition sampling with technical devices so that a much higher spatial sampling density can be achieved. Especially for HM, experimental data for occult and dry deposition are hardly available, and also data for dry deposition of N are very limited. Concentrations of various key metals in moss have been successfully calibrated versus atmospheric deposition levels of the same metals (Berg and Steinnes, 1997). Although the moss concentration data provide no direct quantitative measurement of total deposition, this information can be derived by statistical approaches relating element concentrations in mosses to measured element concentrations in atmospheric deposition (Harmens et al., 2010, 2011, 2015). This way, the spatial resolution of atmospheric HM and N deposition maps can be enhanced (Schröder et al., 2011a; 2011b, 2012, 2014). Since 1990, every five years the European Moss Surveys (EMS) have been providing data on concentrations of HM, and since 2005 concentrations of N in moss (Harmens et al.,